TITLE OF INVENTION

METHOD FOR PRODUCING A HIGH RESOLUTION DETECTOR ARRAY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation-in-part application that claims the benefit of the filing date of Non-Provisional Patent Application Serial No. 09/972,339 filed on October 5, 2001.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

1. Field of Invention

[0003] This invention pertains to a method of producing a scintillator detector array that may be used in various applications, such as, but not limited to, a positron emission tomography detector module or nuclear physics applications. More specifically, it relates to a method of producing a high resolution detector array that can be coupled to photodetectors. In certain applications, the photodetector provides an accurate timing pulse and initial energy discrimination, identification of the crystal interaction, which may include the depth of interaction (DOI).

2. Description of the Related Art

[0004] When constructing scintillator arrays, it is known to use block scintillator arrays with sawcut grooves packed with reflective media. However, this method is not feasible for producing arrays of individual crystals. It is also known to use reflective paint or to use reflector molds made of various reflective media. However, it is often desired to produce light output with greater depth dependence than these types of reflectors are capable of producing.

[0005] Finally, it is also known to hand wrap "plumbers" Teflon® tape around individual detectors as a standard reflector choice for research positron emission tomography cameras. However, plumbers Teflon® tape is not a realistic choice for large cameras and/or cameras that use very small crystals. Further, hand wrapping individual crystals is both time consuming and difficult to do consistently. Hand wrapping with Teflon® tape also limits the reduction of crystal size for future cameras. In addition, plumbers Teflon® tape, or thicker 8mil Teflon® tape, is not an ideal reflector. It stretches and creeps resulting in difficulty in accurately covering that portion of the crystal's surface that is not coupled to a photodetector. The Teflon® tape also has a tendency to become transparent when squeezed, which occurs when making a compact scintillator crystal array, and when glue wicks through it. Moreover, it is difficult to wrap the individual crystals tightly with thicker 8mil Teflon® tape resulting in inaccurate measures of depth dependence.

[0006] What is missing from the art is a method of disposing a reflector between each individual crystal of a high resolution detector array which can efficiently, consistently and accurately cover the desired surfaces of an individual crystal. Accordingly, it is an object of the present invention to provide a method of producing a high resolution detector array having a reflector disposed between individual crystals of the array.

BRIEF SUMMARY OF THE INVENTION

[0007] In one embodiment of the present invention, the fabrication methodology is enhanced by handling scintillator bars rather than single crystals when gluing on the optical film as well as polishing the scintillator bars. Namely, a scintillator boule is cut into bars of a selected dimension, for example 30 mm wide, which then maybe polished. A selected number, N, of these scintillator bars can then be glued together with sheets of an optical film sandwiched between each bar (coating the scintillator bars and optical sheets with an optical adhesive). Suitable optical films include mono-layer or multi-layer, nonwettable reflective films such as polyester films and polyethylene films, including Polyethylene Terephthalate (PET) or Polyethylene Naphthalate (PEN) films. Those skilled in the art will recognize that there are other suitable optical films. The glued bar block is then cut again into bars in a

perpendicular direction, and these new scintillator-optical film bars which then maybe polished. Finally, a selected number, M, of these scintillator-optical film bars are glued together with sheets of optical film sandwiched between each bar; thus creating a polished NxM scintillator-optical film array without having to handle individual scintillator crystals or small pieces of optical film. It will be appreciated by those skilled in the art that while M may be equal to N, M can also be greater than or less than N.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0008] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

[0009] Figure 1 is a perspective view of a detector array constructed in accordance with the prior art in which individual crystals are cut and adhered to a base material, such as a light guide.

[0010] Figures 2a, 2b and 2c are a perspective view of the first steps of the method of the present invention utilizing a single scintillator material.

[0011] Figures 3a, 3b and 3c are a perspective view of the final steps of the method illustrated in Figures 2a, 2b and 2c and the detector array produced by such method.

[0012] Figures 4a, 4b and 4c are a perspective view of the first steps of an alternate embodiment of the method of the present invention utilizing two different scintillator materials.

[0013] Figures 5a, 5b and 5c are a perspective view of the final steps of the method illustrated in Figures 4a, 4b and 4c and the detector array produced by such method.

[0014] Figures 6a, 6b and 6c are a perspective view of the first steps of an additional alternate embodiment of the method of the present invention starting with a stacked scintillator material having a first decay time A_1 and a second decay time A_2.

[0015] Figures 7a, 7b and 7c are a perspective view of the final steps of the method illustrated in Figures 6a, 6b and 6c and the detector array produced by such method.

[0016] Figures 8a, 8b and 8c are a perspective view of the first steps of a further alternate embodiment of the method of the present invention utilizing a first stacked scintillator material having a first decay time A_1 and a second decay time A_2 and a second stacked scintillator material having a first decay time B_1 and a second decay time B_2.

[0017] Figures 9a, 9b and 9c are a perspective view of the final steps of the method illustrated in Figures 8a, 8b and 8c and the detector array produced by such method.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The detector designs produced by the method disclosed herein, along with its alternate embodiments, will enable finer spatial resolution than is achievable with current state of the art detector fabrication methodologies. The method can be utilized to produce a detector array comprised of a single scintillator material, or as described herein, can employ the use of two or more scintillator materials of different decay times. The decay times are used as one of the parameters in determining the scintillator elements loci in position space. Most current detector designs use the decay time for depth of interaction encoding (DOI). Variants of the new design would also be capable of providing this feature.

[0019] In general, the detector fabrication method will provide very high packing fraction i.e. the distance between scintillator elements will be minimized so the detector efficiency will be higher than is currently achievable. Another important feature of the design is that four times as many detector elements will be able to be resolved in position space with no increase in the number of optical detectors; the result will be that the intrinsic spatial resolution will be half of the current designs i.e. we will be able to spatially resolve smaller objects.

[0020] According to one embodiment of the present invention, the method of the present invention entails the following steps. By way of example, it will be recognized that a prior art, standard block detector having dimensions of 52mm wide x 52mm long x 20mm thick

which is segmented into a 12 x 12 array has a crystal pitch of 4.3mm and crystal size of 4.0 mm, as seen in Figure 1 is constructed by arranging discrete cut scintillator crystal elements upon a substrate, resulting in large interstitial spaces which are typically packed with reflector powder. In contrast, according to the method of the present invention, a selected number, N, of bars of scintillator material are cut to a selected dimension, in one embodiment 52mm long x 2mm wide x 20mm thick. In Figures 2 and 3, by way of example, the selected number of bars is twelve. It will be appreciated that while a 12x12 array is depicted in the figures, the method of the present invention could also be utilized to produce an 8x8 array, a 24x24 array, a 4x4 array etc. It will also be appreciated that the method could also be utilized to produce NxM arrays where $M \neq N$. While the present method could be utilized to produce an NxM, (it being understood that M may or may not equal N), detector array of a single scintillator material (as illustrated in Figures 2a, 2b, 2c, 3a, 3b and 3c), in other embodiments, the method of the present embodiment could be utilized to produce detector arrays utilizing two different scintillator materials, (see Figures 4a, 4b, 4c, 5a, 5b and 5c), utilizing a stacked scintillator material having a first decay time A_1 and a second decay time A_2, (see Figures 6a, 6b, 6c, 7a, 7b and 7c) or utilizing two different scintillator materials in which the first scintillator material is a stacked scintillator material having a first decay time A_1 and a second decay time A_2 and the second scintillator material is a stacked scintillator material having a first decay time B_1 and a second decay time B_2, (see Figures 8a, 8b, 8c, 9a, 9b and 9c).

[0021] It will be recognized by those skilled in the art that there are a number of known scintillator materials that are utilized in detector technologies, such as intrinsic scintillators such as, but not limited to, BGO, activated scintillators such as, but not limited to, NaI(Tl), LSO, GSO, YSO, LYSO, LGSO etc, and ceramic scintillators from which one skilled in the art could fabricate a detector array constructed in accordance with the present invention. As illustrated in Figures 2-3, when producing a scintillation detector array from a single scintillator material, N bars **20** are cut from a block **10** of a selected scintillator material. The bars **20** in Figure 2b would then be polished. It will be understood that the polishing can be accomplished by either a chemical etch process (inexpensive approach) or a mechanical polishing process (expensive approach); either choice can be made. The polished bars are

then coated with an adhesive of selected index of refraction. Suitable adhesives include epoxies, such as, but not limited to, Epotek 301-2, silicon adhesives such as, but not limited to, GE 656, or silicon encapsulants such as, but not limited to, Sylgard 186, Sylgard 184 or GE 615. Those skilled in the art will recognize that other adhesives having a suitable index of refraction may also be used. A thin (50- 200 micron) optical film **40** is then bonded to the scintillator bar using the selected adhesive. Suitable optical films include mono-layer or multi-layer, nonwettable reflective films such as polyester films and polyethylene films, including, but not limited to, Polyethylene Terephthalate (PET) or Polyethylene Naphthalate (PEN) films. Further, it will be appreciated by those skilled in the art that the preferred optical film is reflective, and, to this end, can be loaded with a reflective material such as $BaSO_4$, MgO, SiO_2, powdered Teflon, $CaC0_3$ or $Ti0_2$ etc. and/or combinations thereof. Those skilled in the art will recognize that there are other suitable optical films. Further, those skilled in the art will recognize that there are other suitable optical films whose reflective properties do not require the addition of additional reflective loading. The scintillator bars are then laminated together. The pattern would be a layer of scintillator **20** followed by a layer of adhesive and thin optical film **40**, followed by a layer of scintillator **20**. This process is repeated until all N layers are laminated together, See Figure 2c. The assembly is then allowed to cure. Once fully cured the laminated block is subjected to a second sawing operation in which the laminated block is then cut into M bars **50** of a selected thickness by cutting across the laminated bars, see Fig. 3a. As stated above, M may or may not be equal to N. This results in M bars **50** of a selected dimension, for example 2mm wide x 52mm long x 20mm thick. Note though that in this case each bar contains N scintillator elements **20'**. These N bars **50** are then polished. The polished bars are then coated with an adhesive of selected index of refraction and optical film **40** is then bonded to the scintillator bar **50** using the selected adhesive, see Fig. 3b. The scintillator layers are then laminated together using the process described above, see Fig. 3c. The process results in an NxM scintillator element array. As stated above, the figures illustrate and exemplary 12x12 detector array. However, as has been stated, it will be appreciated that other array sizes, could be produced in accordance with the method of the present invention, and that M may or may not equal N.

Further, it has been found that the detector array can be tuned by selecting the thickness of the optical film **40** thereby allowing selective transmission of light through optical film **40**.

[0022] In another embodiment, illustrated in Figures 4-5, a detector array utilizing two different scintillator materials is produced. In this embodiment 1/2 N bars **20** are cut from a block **10** of a first selected scintillator material of a first selected decay time while 1/2 N bars **30** are cut from block **15** of a second selected scintillator material of a second selected decay time. The bars **20** and **30** respectively in Figure 4b would then be polished. The polished bars are then coated with an adhesive as described above. A thin (50- 200 micron) optical film **40**, as described above, is then bonded to the scintillator bar using the selected adhesive. The scintillator bars are then laminated together. The pattern would be a layer of scintillator **20**, of decay time x, followed by a layer of adhesive and thin optical film **40**, followed by a layer of scintillator **30** of decay time y, followed by a layer of adhesive and thin optical film **40** followed by a layer of scintillator **20** of decay time x. This process is repeated until all N layers are laminated together, See Figure 4c. It being understood that the composite of the layer of scintillator **20** and the optical film **40** is affixed to the adjoining composite of scintillator **30** and optical film **40** with the selected adhesive and so on. The assembly is then allowed to cure. Once fully cured the laminated block is subjected to a second sawing operation in which the laminated block is then cut into a selected number M bars **50** of a selected thickness by cutting across the laminated bars, see Fig. 5a. This results in M bars **50** of a selected dimension, for example 2mm wide x 52mm long x 20mm thick. Note though that in this case each bar contains 1/2 N scintillator elements **20'** and 1/2 N scintillator elements **30'**. These M bars **50** are then polished. The polished bars are then coated with an adhesive of selected index of refraction and optical film **40** is then bonded to the scintillator bar **50** using the selected adhesive, see Fig. 5b. The scintillator bars **50** are then laminated together using the process described above except that every other layer is rotated 180 degrees. This rotation results in a checkerboard pattern of alternating scintillation crystals of different decay times, see Fig. 5c. The process results in an NxM scintillator element array in which M may or may not equal N. Further, it will be appreciated that a detector array produced in accordance with the method of the present invention can be utilized in

conjunction with light guides which may be either "active" or "inactive", segmented or continuous, and if segmented then either "inverted" or "non-inverted".

[0023] It will be recognized by those skilled in the art that the decay times of certain scintillator materials, activated Lutetium Oxyorthosilicate and activated Gadolinium Oxyorthosilicate to name a couple, are tuneable, such that a block of detector material could be constructed of a first block of a selected scintillator material having a selected decay time A_1 optically bonded to a second block of the same selected scintillator material having a decay time A_2. See Figure 6a. As illustrated in Figures 6-7, when producing a scintillation detector array from a single scintillator material, N bars **20** are cut from a block **10′** of a selected scintillator material. The block **10′** is constructed of a first layer **12** of the selected scintillator material having decay time A_1 which is optically bonded to a second layer **14** of the selected scintillator material having decay time A_2. The bars **20** in Figure 6b would then be polished. The polished bars are then coated with an adhesive, as described above. A thin optical film **40**, as described above, is then bonded to the scintillator bar using the selected adhesive. The scintillator bars are then laminated together, taking care not to invert the orientation of the layers with respect to decay time. The pattern would be a layer of scintillator bar **20** followed by a layer of adhesive and thin optical film **40**, followed by a layer of scintillator bar **20**. This process is repeated until all N layers are laminated together, See Figure 6c. The assembly is then allowed to cure. Once fully cured the laminated block is subjected to a second sawing operation in which the laminated block is then cut into M bars **50** of a selected thickness by cutting across the laminated bars, see Fig. 6a. As stated above, M may or may not be equal to N. This results in M bars **50** of a selected dimension, for example 2mm wide x 52mm long x 20mm thick. Note though that in this case each bar contains N scintillator elements **20'**. These N bars **50** are then polished. The polished bars are then coated with an adhesive of selected index of refraction and optical film **40** is then bonded to the scintillator bar **50** using the selected adhesive, see Fig. 6b. The scintillator layers are then laminated together using the process described above, see Fig. 6c. The process results in an NxM scintillator element array. As stated above, the figures illustrate and exemplary 12x12 detector array. However, as has been stated, it will be appreciated that

other array sizes, could be produced in accordance with the method of the present invention, and that M may or may not equal N.

[0024] Further, as illustrated in Figures 8-9 a detector array utilizing two different scintillator materials in which the first scintillator material consists of a first block **12** of a selected scintillator material having a selected decay time A_1 optically bonded to a second block **14** of the same selected scintillator material having a decay time A_2, and the second scintillator material consists of a first block **17** of a selected scintillator material having a selected decay time B_1 optically bonded to a second block **19** of the same selected scintillator material having a decay time B_2. See Figure 8a. In this embodiment 1/2 N bars **20** are cut from block **10'** and 1/2 N bars **30** are cut from block **15'**. The bars **20** and **30** respectively in Figure 8b are then polished. The polished bars are then coated with an adhesive as discussed above, a thin optical film **40**, as described above, is then bonded to the scintillator bar using the selected adhesive. The scintillator bars are then laminated together, again taking care not to invert the bars with respect to decay times. The pattern would be a layer of scintillator bar **20**, followed by a layer of adhesive and thin optical film **40**, followed by a layer of scintillator bar **30**, followed by a layer of adhesive and thin optical film **40** followed by a layer of scintillator bar **20**. This process is repeated until all N layers are laminated together, See Figure 4c. It being understood that the composite of the layer of scintillator **20** and the optical film **40** is affixed to the adjoining composite of scintillator **30** and optical film **40** with the adhesive and so on. The assembly is then allowed to cure. Once fully cured the laminated block is subjected to a second sawing operation in which the laminated block is then cut into a selected number M bars **50** of a selected thickness by cutting across the laminated bars, see Fig. 5a. This results in M bars **50** of a selected dimension, for example 2mm wide x 52mm long x 20mm thick. Note though that in this case each bar contains 1/2 N scintillator elements **20'** (of decay time A_1 and A_2) and 1/2 N scintillator elements **30'** (of decay time B_1 and B_2) in alternating fashion. These M bars **50** are then polished. The polished bars are then coated with an adhesive of selected index of refraction and optical film **40** is then bonded to the scintillator bar **50** using the selected adhesive, see Fig. 3b. The scintillator bars **50** are then laminated together using the process described above except that every other layer is rotated 180 degrees, again taking care that the bars are not inverted with respect to decay

time. This rotation results in a checkerboard pattern of alternating scintillation crystals of different decay times, see Fig. 5c. The process results in an NxM scintillator element array in which M may or may not equal N.

[0025] From the foregoing description, it will be recognized by those skilled in the art that a method of disposing a reflector between each individual crystal of a high resolution detector array which can efficiently, consistently and accurately cover each of four sides of an individual crystal has been provided. In this regard, the present invention provides a method of producing a high resolution detector array having a reflector disposed between individual crystals of the array. Further, the present invention provides a method for producing a high resolution detector array which will provide very high packing fraction i.e. the distance between scintillator elements will be minimized so the detector efficiency will be higher than is currently achievable and which eliminates the need to hand wrap individual crystals.

[0026] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.